Method for conversion of waveguide modes, mode-converting arrangement and antenna arrangement

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The present invention relates to a method for conversion of waveguide modes from a mode of type TM_{01} to mode of type TE_{11} for transmission of power within the microwave range. The invention also relates to a
10 mode-converting arrangement for conversion of waveguide modes from a mode of type TM_{01} to mode of type TE_{11} for transmission of power within the microwave range, comprising an incoming waveguide for reception of power of the type TM_{01}, an outgoing waveguide for outputting
15 power of the mode type TE_{11} and a waveguide-mode-converting section arranged between the incoming and outgoing waveguides. In addition, the invention relates to an antenna arrangement with mode converter according to the invention.

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In certain situations, where power is to be transferred from, for example, a microwave generator to an antenna, it is of interest to change from one waveguide mode to one or more other modes. With power generation in
25 certain microwave generators, the power is delivered typically in a so-called TM_{01} mode in a circular waveguide. For a more detailed description of the mode type, refer to "Balanis, Advanced Engineering Electromagnetics, Wiley 1989". This mode is often not
30 suitable for exciting an antenna, for example of the waveguide horn type, due to the fact that it gives a toroidal radiation pattern with a zero depth in the axial direction of the waveguide. In many situations, it is therefore of interest to deliver the power in a
35 circular waveguide in TE_{11} mode. If linear polarization is of interest, the power is delivered accordingly in one TE_{11} mode. For the generation of circular polarization in an antenna, the power can be delivered

in two orthogonal TE_{11} modes excited 90 degrees out of phase in time.

Conversion of TM_{01} mode to TE_{11} mode is known in
5   connection with the exciting of antennas, see for example US patent document 4 999 591. The mode converter described in this document has limitations regarding polarization and can be difficult to manufacture with precision due to its asymmetrical
10   design.

Mode converters for converting power from the circular so-called TM_{01} mode to one or two TE_{11} modes are difficult to achieve, particularly if they are to cope
15   with high power.

The object of the present invention is to achieve a method for conversion of waveguide modes, a mode-converting arrangement, and an antenna arrangement
20   which can cope with high powers and can handle different types of polarization in different variants and which mode-converting arrangement has an essentially symmetrical shape and is relatively simple in its construction.
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The object is achieved by means of a method characterized in that incoming power of mode type TM_{01} is divided between two or more waveguides with cross-sections that are essentially in the shape of circle
30   sectors, in that the divided power is phase-shifted by the waveguides in a subsequent phase-shift section by means of waveguides with cross-sections essentially in the shape of circle sectors with different radii, after which the waveguides are changed into a common
35   essentially circular waveguide that emits an outgoing power of mode type TE_{11}, and a mode-converting arrangement characterized in that the waveguide-mode-converting section comprises at least one input section

for dividing the received power into two or more
components and a phase-shift section at the output side
of the input section with an allocated waveguide for
each power component, with the waveguides being
5   designed with cross-sections that are essentially in
the shape of circle sectors with different radii
emanating from a common centre and such that the cross-
sections in the shape of circle sectors together
essentially cover 360 degrees. The change is carried
10 out in a plurality of sections where, in particular,
the design of the phase-shift section with different
radii is of decisive significance for the function. The
mode-converting arrangement according to the invention
and defined above is relatively narrow-band and can
15 cope with high powers. By placing the mode-converting
arrangement in a vacuum in association with the
microwave generator, the arrangement can cope with even
higher powers.

20 According to an advantageous method, the conversion of
waveguide mode from mode type TM_{01} to mode type TE_{11} is
caused, in an intermediate stage comprising four
separate waveguides, to assume four modes each of which
has a field configuration that constitutes a quarter of
25 a so-called TE_{21} mode in a corresponding circular
waveguide. By means of this method, the power in a
circular TM_{01} mode can be converted to two TE_{11} modes 90
degrees out of phase, for the generation of circular
polarization in an antenna.
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The mode-converting arrangement is advantageously
provided with a mode-mixer section included in
connection with the outgoing waveguide, which mode-
mixer section comprises a change from a plurality of
35 waveguides with cross-sections in the shape of circle
sectors to one waveguide with an essentially circular
cross-section. In the mode-mixer section, two basic
modes of TE_{11} type are propagated first of all. The

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change in the mode-mixer section can be designed as an abrupt change. Alternatively, the change is designed to be gradual, by the change having an extent in the transmission direction that corresponds to at least
5 $\lambda_0/4$, where λ_0 denotes the free-space wavelength for the centre frequency in the band that is transmitted by the arrangement. In a proposed embodiment, the output of the mode-mixer section forms the outgoing waveguide of the arrangement. This output can, for example, be
10 connected to a conical-shaped waveguide horn.

According to an advantageous embodiment of the mode-converting arrangement, a balance section is included, connected to the output side of the phase-shift section
15 and comprising waveguides with cross-sections that are essentially in the shape of circle sectors with the same radii in order to balance the field configurations of the waves that leave the different waveguides of the phase-shift section.
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According to yet another advantageous embodiment of the mode-converting arrangement, there is an intermediate section between the input section and the phase-shift section, which intermediate section comprises a
25 plurality of waveguides with cross-sections in the shape of circle sectors and essentially identical radii.

In two suitable embodiments, the input section of the
30 mode-converting arrangement is designed to divide the received power into two or four components respectively. By means of the division into two components, conversion can be carried out to one TE_{11} mode, while division into four components is suited for
35 conversion of the power to two TE_{11} modes which are 90 degrees out of phase with each other.

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According to yet another advantageous embodiment of the invention, the input section comprises thin ridges for dividing the received power, which ridges increase in size in the transmission direction from the periphery

5   of the input section inwards towards the middle of the input section so that they meet at the output side of the input section. The ridges can be designed to increase in size continuously or in steps in the transmission direction.

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The invention will be described below with reference to the attached drawings, in which:

Figure 1 shows an example of a mode-converting

15 arrangement according to the invention with change to two TE_{11} modes excited 90 degrees out of phase.

Figure 2 shows a cross-section through a phase-shift section comprised in the mode converter according to

20 the invention.

Figure 3 shows schematically the transverse E-fields for the waveguide modes TE_{11}, TM_{01} and TE_{21}.

25 Figure 4 shows schematically the transverse E-fields in different parts of the mode-converting arrangement according to Figure 1.

Figure 5 shows schematically the transverse E-fields in

30 different parts of a mode-converting arrangement according to the invention with change to one TE_{11} mode.

Figure 6 shows a cross-section through a simpler phase-shift section comprised in a mode-converting

35 arrangement according to the invention.

Figures 7a and 7b show in side view two different
examples of ridge elements that can be included in the
mode-converting arrangement according to the invention.

5   The appearance of the transverse E-fields for the three
    modes that are principally of relevance for the
    invention is described schematically, prior to the
    description below of the mode-converting arrangement.
    Figures 3a and 3b show the transverse E-fields for two
10 orthogonal TE_{11} modes. Figure 3c shows the transverse
    field for the TM_{01} mode. Figure 3d and Figure 3e show
    the transverse E-fields for two TE_{21} modes.

    The example shown in Figure 1 of a mode-converting
15 arrangement with change to two TE_{11} modes comprises an
    incoming waveguide 1, an input section 2, an
    intermediate section 3, a phase-shift section 4, a
    balance section 5 and a mode-mixer section 6. The
    output of the mode-mixer section is designed to be
20 connected directly or via a separate outgoing waveguide
    to the exciter unit, typically a waveguide horn, in an
    antenna. The construction and tasks of the sections
    involved are described below, step by step, starting
    with the input side of the mode-converting arrangement.
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    The incoming waveguide 1 consists here of a circular
    hollow guide that is assumed to be able to propagate at
    least five modes, namely two TE_{11} modes, so-called basic
    modes, the TM_{01} mode and two TE_{21} modes. The only excited
30 mode is, however, the TM_{01} mode.

    The incoming waveguide 1 is followed by the input
    section 2. The input section has a circular cylindrical
    shape and comprises four thin rounded ridges 2.1-2.4.
35 The ridges are separated at 90 degrees from each other
    along the circular cylindrical surface of the input
    section and run parallel to the axis of rotation for
    the circular cylindrical surface. The ridges are shaped

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to gradually increase in size towards the axis of
rotation along the direction of transmission of the
mode-converting arrangement so that they meet at the
output side of the input section. Figures 4a-4c show
5   schematically the field configuration for the
transverse E-fields as the ridges gradually increase in
size in the input section 2. Figure 4a shows the field
configuration close to the input side of the input
section, Figure 4b shows the field configuration
10   further into the input section and Figure 4c shows the
field configuration on the output side of the input
section where the ridges meet. No high field strengths
arise in the input section when the distance between
the ridges is made smaller on account of the fact that
15   the transverse electrical field, the E-field, on both
sides of the middle of the waveguide has the opposite
direction for the TM_{01} mode. This is essential in order
for the waveguide change to be able to withstand high
power. The input section is suitably given a length
20   longer than or equal to $\lambda_0/4$ and for example λ_0, where
λ_0 denotes the free-space wavelength of the centre
frequency in the band. The input section must have a
certain length in order that the mode-converting
arrangement will not be mismatched and give a high
25   reflection coefficient. Where the ridges 2.1-2.4 meet
at the output side of the input section 2, the original
circular waveguide has changed to four waveguides with
cross-sections that are in the shape of 90 degree
circle sectors.
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Figure 7a shows in side view a ridge 2.1 comprised in
the input section 2, according to the embodiment
described with reference to Figure 1. The ridge has an
edge 2.7 that increases in size continuously.
35   Alternatively, it is however possible to introduce an
edge 2.8 with a stepped increase as shown in Figure 7b.
A suitable step length is $\lambda_0/4$.

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The four waveguides 3.1-3.4 form the intermediate section 3. In these waveguides only one mode is now propagated in each waveguide 3.1-3.4. These modes each constitute "one quarter" of a so-called TE_{21} mode for
5   the original waveguide and have the same propagation constant as the TE_{21} modes that can propagate in the original circular waveguide. The extension of the thin ridges 2.1-2.4 into the intermediate section defines a symmetry plane in relation to which the E-field for the
10 TE_{21} mode is orthogonal in the incoming circular waveguide 1. The introduction of the ridge extensions as walls has not changed anything as far as the TE_{21} mode is concerned, as the edge conditions in the waveguides 3.1-3.4 of the intermediate section 3
15 maintain the symmetry and the field configuration.

Via the intermediate section 3, the four waveguide modes are excited further inside the phase-shift section 4. The phase-shift section contains similarly
20 four waveguides 4.1-4.4. The ridge extensions in the intermediate section continue into the phase-shift section and form four walls which together with the outer boundaries of the phase-shift section form the four waveguides 4.1-4.4. The four waveguides have
25 cross-sections that are in the shape of circle sectors with four different radii r_1-r_4. A schematic cross-section through the phase-shift section 4 is shown in Figure 2. The different radii r_1-r_4 give different propagation constants. During propagation through the
30 phase-shift section, the waves in the different waveguides are therefore given a phase shift relative to each other. Theoretically, a length is required that is longer than $\lambda_0/2$ in order to obtain a phase shift of 180 degrees between two of the waveguides and
35 consequently $\lambda_0/4$ in order to obtain a phase shift of 90 degrees. In practice, however, a considerably longer length is required in order to achieve this phase shift, particularly if we want to obtain different

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phase shifts between different pairs of waveguides. By
means of a suitable choice of the length of the phase-
shift section 4 and the radii r_1-r_4 of the individual
waveguides 4.1-4.4, a phase shift of 180 degrees is

5   arranged between the waveguides in each pair of
diagonally opposite waveguides, that is between 4.1 and
4.3 and between 4.2 and 4.4. In addition, the radii r_1-r_4 are selected in such a way that a phase shift of 90
degrees is obtained between two adjacent waveguides. A

10   suitable length of the phase-shift section can be $2\lambda_0$.

The phase-shift section 4 changes into a balance
section 5 by means of the four waveguides 4.1-4.4 in
the phase-shift section 4 being given the same radius.

15   In this way, the waveguides 5.1-5.4 are given identical
cross-sections that are in the shape of circle sectors.
The radius in the waveguides is so small that only one
mode can propagate in each waveguide. The length of the
balance section is preferably $\geq \lambda_0/4$. The task of the

20   balance section is to balance the field configurations
of the different waveguides prior to the change to the
subsequent mode-mixer section.

In the mode-mixer section 6, the dividing walls are

25   arranged so as to disappear. The change can be carried
out abruptly without affecting significantly the
matching of the mode-converting arrangement.
Alternatively, the change can be carried out gradually.
The mode-mixer section is essentially a circular

30   waveguide section without dividing walls. The mode-
mixer section is preferably given a radius such that
only three modes can propagate, namely two degenerated
basic modes (TE_{11}), and one first higher-level mode
(TM_{01}). The latter is not excited significantly. The

35   mode-mixer section 6 is preferably dimensioned to have
a length that exceeds $\lambda_0/4$ and can, for example, have a
length amounting to $\lambda_0/2$. The task of the mode-mixer
section is to excite the required TE_{11} modes 90 degrees

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out of phase to obtain a circular polarization. This is
carried out in a natural way by means of the phase
shifts that are achieved in the phase-shift section 5.
The output of the mode-mixer section can, for example,
5   be connected to a horn antenna that is conical shaped
and/or has corrugated walls, if required for
illumination of a reflecting antenna. Figures 4d and 4e
show schematically the appearance of the transverse E-
fields at the input of the mode-mixer section, where
10   the time difference between the field configurations is
a quarter of a period.

The example described above concerned conversion from
TM_{01} mode to two TE_{11} modes, 90 degrees out of phase. In
15   a somewhat simplified embodiment, the mode-converting
arrangement can be designed to convert an incoming TM_{01}
mode to one TE_{11} mode. In such a simplified mode-
converting arrangement, the input section 2 has only
two ridges that increase in size from two
20   diametrically-opposite positions on the circular
cylindrical surface of the input section. The
intermediate section 3 will then consist of two
waveguides with semicircular cross-section. In the
phase-shift section 4, that now consists of two
25   waveguides with semicircular cross-section and
different radii, a phase shift of 180 degrees is
introduced between the modes propagating in the
waveguides. Figure 6 shows a cross-section through the
phase-shift section 4 with the two radii being
30   designated by r_5 and r_6. The balance section 5 and mode-
mixer section 6 are introduced analogously with the
description above of the generation of two TE_{11} modes,
with, however, the balance section here only comprising
two waveguides.
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Figure 5 shows schematically the transverse E-fields
for the simplified embodiment. Figures 5a to 5c relate
to the same cross-section within the input section 2 as

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described above for the embodiment shown in Figure 1,
that is at the input of the input section, somewhere in
the middle of the input section and at the output side
of the input section. In the simplified embodiment,
5   there are only two ridges 2.5 and 2.6 that increase in
size to become one complete dividing wall. Figure 5d
shows the appearance of the field configuration at the
input of the mode-mixer section 6.

10   The invention is not limited to the embodiments
described in the above as examples, but can be modified
within the framework of the following patent claims.